Integration study and first test results of the CMS Muon Barrel Alignment system

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Abstract

The Muon Barrel Alignment system is based on the precise measurement of LED positions and signals of different sensors located in several predetermined places of the barrel. These data are collected by 36 PC/104 board computers. The board computers are organized in a network and controlled by a workstation, which communicates with the DCS system providing the precise status information of the barrel muon chambers.

The aim of this paper is to describe the communication flow, the data hierarchy, the data structure, and the distribution of the tasks among the elements of the system. The first simulation and test results are also discussed.

I. Introduction

The CMS barrel muon alignment system is briefly described in [1]. Its main elements are LED light sources mounted on the 250 barrel muon chambers and 36 rigid structures called MABs. The MABs are holding video cameras and also a tiltsensor and temperature and humidity sensors. The complete system contains additional LED sources mounted on the MABs and on long rigid bars called z-bars. The total number of LED sources is about 10500, the number of video cameras is 600.

The electronics on each MAB is controlled and the data are collected by a PC/104 board computer (BC) located inside the detector close to its MAB. The BCs evaluate the captured video data and calculate the centroids of the LED images. Furthermore they process the signals of the analog sensors and on request from the SCADA (Supervisory Control and Data Acquisition) workstation (SCW) sends these data to refresh the central database. As all the BCs perform the same tasks, they are booted from a central computer, where a complete Linux development environment is installed. New software versions (system and application) are developed and tested centrally and all the BCs are updated via Ethernet link. A heavily tailored subsystem of this Linux is also stored on the DiskOnChip flash memory storage device of every BC.

The SCADA system supervises part of the HW (the LEDs mounted on the muon chambers) through direct HW control and controls the rest of the system by sending commands to the BCs and receiving results from them through the Ethernet network, using the DIM protocol. The BCs are highly autonomous DAQ servers answering requests from the SCADA client and processing the vast majority of the measured raw data. The central database is located on the SCADA workstation, but –in order to minimize data transfer through the network– some data are duplicated temporarily on the BCs. The user interface is provided and the database is supervised by the specialized process supervising and visualization software, PVSS II.

As it was mentioned above the building blocks of the Muon Barrel Alignment (MBA) system are located inside the CMS detector, therefore have to survive the high magnetic and radiation fields during the 10 years of operation. This extreme environmental condition causes severe difficulties not only in the sensor part but also in the BC architecture. The high magnetic field makes impossible the use of standard inductive elements, DC/DC converters and isolation transformers.

A general view of the alignment system is shown in Figure 1. The paper describes typical position measuring results obtained at the LED holder and chamber calibration test bench. A few technical details of the BC are also presented.

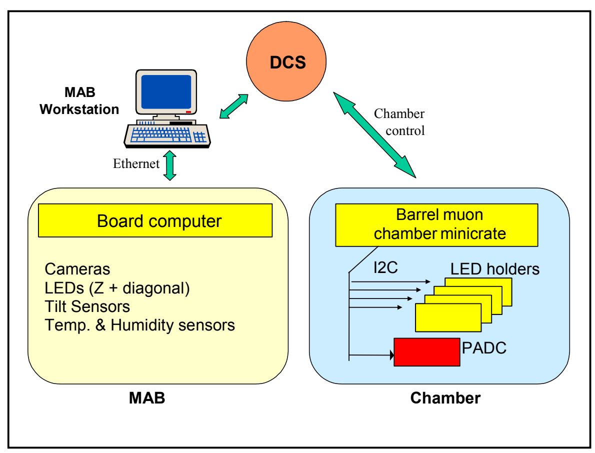

Figure 1: The building blocks of the MBA electronics

II. MBA calibration database

The determination of the positions of the barrel muon chambers in the CMS coordinate system requires a database structure containing precise geometry data about the locations of the LED sources with respect to the anode wires of the barrel muon chambers. This calibration database is obtained by calibration of the positions of the LED sources on the LED-holders and the positions of the LED holders on the chambers. The correct parameter settings during the system operation (e.g. the currents of the LED sources) are also obtained from the calibration database. The records of the calibration database have to represent the current coordinates of the muon chambers all the time. The organization of these records will follow the topological arrangement of the detector structure.

The closely HW-related activity tasks (i.e. the centroid measurement of the light sources) of the Muon Barrel Alignment is carried out by the BCs and basically only these results are transmitted to the SCADA workstation. The full geometrical reconstruction is then done by a separate specialised reconstruction program which operates on the same database. When the geometrical reconstruction is ready the database is refreshed and the SCADA system can access the updated coordinates.

III. CALIBRATION OF THE MBA ELEMENTS

The positions of the LED sources mounted on the barrel muon chambers are measured in two steps. First the LED holders containing the LED sources are calibrated. Then the LED holders are mounted on the chambers and the full chamber is calibrated.

A. LED holder calibration

The bench used for LED holder calibration is shown in Figure 2. The LED holder is mounted on the calibration tool sitting on a precision X-Y table driven by stepper motors. The LED sources are observed by video cameras on both sides of the calibration tool. During the calibration procedure the light spot of the LEDs were sequentially moved to the same position on the picture of the video camera. The relative coordinates of the LEDs can be derived from the X and Y positions read from the precision table. The accuracy of the measurement is better than 10 micrometer. In Figure 3 the scatter-plot demonstrates the statistics of the repeated measurements of one light source.

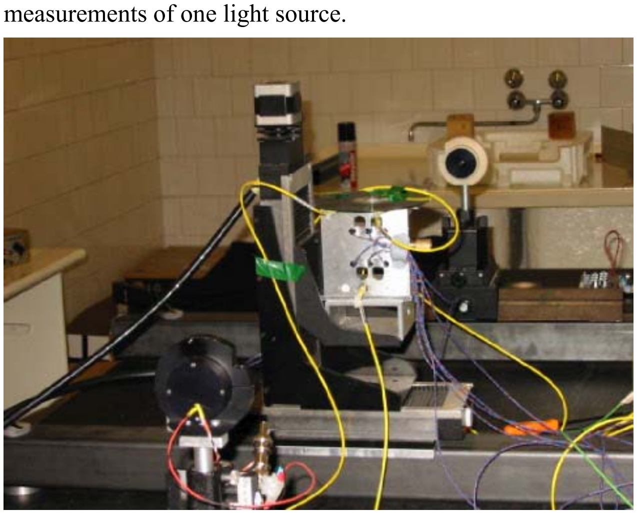

Figure 2: The LED holder calibration bench

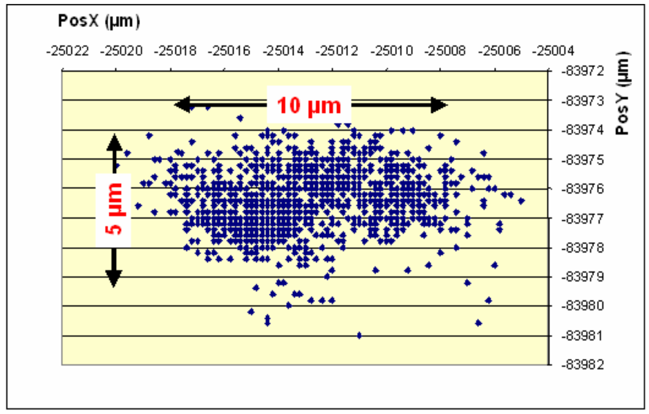

Figure 3: The LED source measurement accuracy

B. Chamber calibration

The 4x5 m^2 chamber calibration bench installed at CERN is shown in Figure 4. The bench is designed to calibrate all the chamber types of different widths in the range of 2 – 4m. The positions of the LED holders on the chambers are measured by video cameras with known positions. The position of the chamber body in the laboratory coordinate system is measured by photogrammetry [2]. Combining the two measurements the position of the LED holders can be determined with 60-70 micrometer precision with respect to the chamber body. The chamber database contains the full geometry of each chamber including the characteristics of the LED holders mounted on it and its location in CMS.

On Figure 5 the data flow during chamber calibration can be seen. The input tables of the chamber calibration database are filled by the two measurement processes described above. The combination of these measurements and the fork calibration results is done by a geometrical reconstruction program (the same as designed to be used in the full system). Its results are uploaded back into the result tables of the Chamber Calibration Database. Besides to this all data in this database can be searched and supervised through a custom designed web interface.

Figure 4: The chamber calibration bench at CERN

The logical diagram of the database creation during the calibration process is shown in Figure 5.

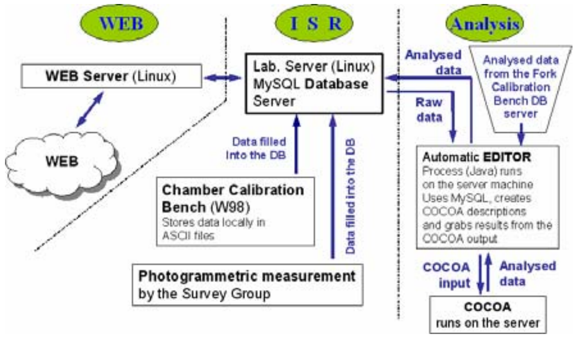

Figure 5: Structure of the data flow during chamber calibration

IV. MBA INTEGRATION STUDIES

A. Integration of LED holders and PADC

The electronic components located on the muon chambers can be seen in Figure 1. These are four LED holders and one PADC pressure sensing module controlled by the intelligent Minicrate.

The CMS Detector System of the LHC will use gas filled Drift Tube (DT) Chambers to detect muons. The pressure in the chambers has to be kept at a constant level, and this level has to be monitored. A difference from the nominal pressure value will influence the results of the measurement of particle momentum. The RWTH Aachen group, which took part in the manufacturing of the chambers, developed the PADC board to regularly read out the pressure sensors and to send the data to the Detector Control System (DCS) of CMS. PADC boards will be installed on each of the 240 pieces of Barrel Muon Chambers.

Both the LED holder modules and the PADC can be controlled by the standard I^2C protocol. The protocol allows connecting up to 127 individual devices with different addresses on the same bus. To optimize the arrangement, cabling and low voltage distribution of these units, it was decided to connect all these modules with one I^2C bus. The consequence of this direct connection was that the clock frequency of the I^2C transfer had to be identical (1 kHz) for all modules.

The Minicrate communicates with the DCS and the commands from the supervisory level are distributed to the specific modules through I^2C bus. The power of the LED holder modules is also supplied by the Minicrate, but the PADC has an own power unit.

As in the development phase the access of the Minicrate is insufficient, a diagnostic tool was developed and manufactured by the Debrecen group for emulation of the Minicrate functions. This tool was used successfully during the chamber calibration at CERN. The photo in Figure 6 illustrates the integrated modules controlled by the diagnostic device through I^2C bus.

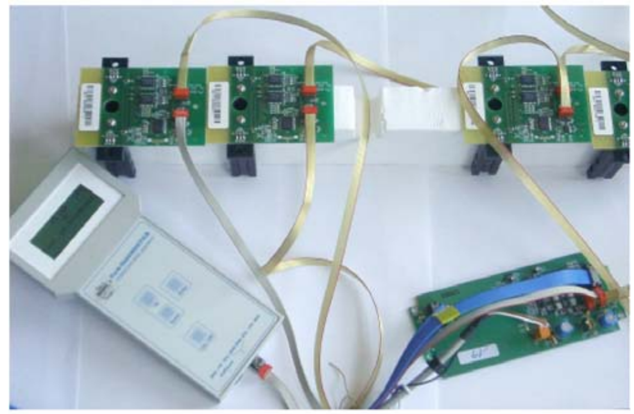

Figure 6: The LED holders and the PADC module controlled by the portable diagnostic box.

B. Board Computer layers

The local control, the collection of the data from the video cameras and the sensors as well as the calculations of the centroids of the LED light spots are performed by local computers installed on the MABs. These computers are built up as a stack of PC/104 cards and the different layers can be seen in Figure 7.

The BC performs the following tasks:

- reading and saving the pictures of the connected cameras,
- calculating the centroids of the LED light spots,
- reading the analog signals of the tilt sensors,
- switching on/off z-bar LEDs and LEDs mounted on the MAB,
- publish services and available commands for the DIM name server,
- produce watchdog signals for the DIM name server.

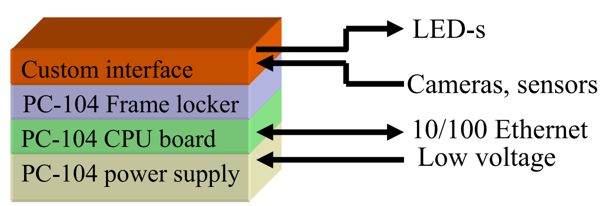

Figure 7: Layers of the Board Computer

As the BC will be placed on the CMS Barrel, it has to function in radiation and magnetic fields. The previously chosen PC104 module (Tri-M System MZ104 [3]) passed the radiation hardness tests but it failed the magnetic test. Two sources of problem were identified, the Ethernet isolation transformer and the step-down DC-DC converter on the CPU board. The fist failure was easy to overcome by removing the transformer which was sensitive to the magnetic field. However, the latter problem could not be solved, as in the specific construction the DC-DC converters could not be removed and a new module had to be selected.

The new module is CoreModule420 PC/104 computer, manufactured by Ampro [4]. This module has similar performance and similar Ethernet part as the previous one. The AMPRO board lacks DC-DC converter for the processor core, the only coil on the board is for the LCD display, which is not needed in the present application. It has a great advantage, namely the programs can be stored on CompactFlash card beside the DiskOnChip. The block diagram of the AMPRO CoreModule420 can be seen in Figure 8.

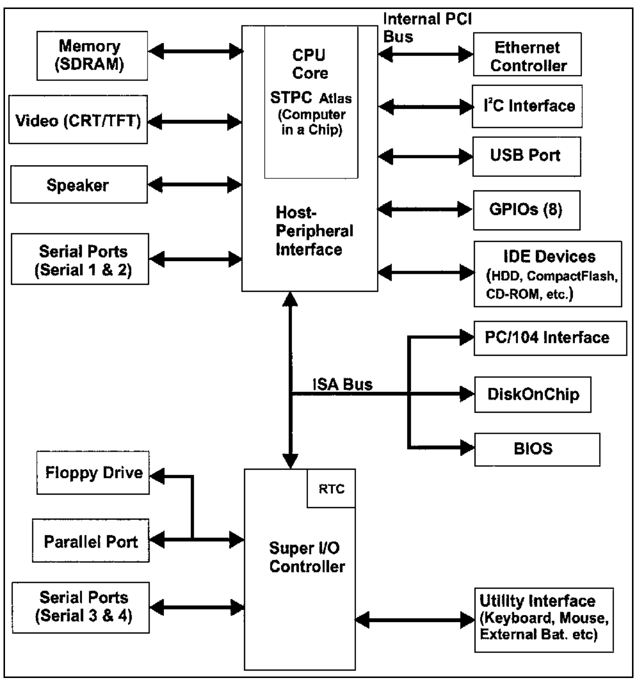

Figure 8: AMPRO CoreModule420 block diagram

The frame locker is manufactured by Ajeco [5]. It will be read out by a custom written software under LINUX. The pictures digitized by the frame locker will be transferred by DMA to the memory of the BC. The Ajeco frame locker passed both the radiation and the magnetic tests, so all the needed pieces were purchased (36 modules to be built in and 14 as reserve).

The custom interface, seen in Figure 7, has to connect all the sensors around the BC to the CPU board. There are four temperature and humidity sensors on each rigid mechanical structure to monitor the environment. The orientation of the rigid mechanics is determined by tilt sensors giving precise analog signal. This voltage has to be digitized and fed to the CPU using the I^2C interface located on the board. There is a demand to locate up to 32 LEDs in the vicinity of the BC. These LEDs are controlled by the BC via SPI bus.

As the Ajeco frame locker has only four direct video inputs, a custom built 3×8 video multiplexer is also located on the custom interface to enable the use of up to 24 video sensors distributed over the rigid mechanical structure.

The low voltage supply also forms one layer of the PC/104 stack. All the incoming low voltage lines are monitored by the custom interface.

V. CONCLUSIONS

1200 pieces of LED holders are calibrated and delivered to CERN. The assembly of the MBA elements on the DT chambers has a good progress.

All the necessary components on the MAB (BC, camera, proximity sensor, tilt sensor, humidity and temperature sensor) have been defined and the procurement is on the way.

The SW integration has to be validated and updated after the final version of the BC is completed.

VI. ACKNOWLEDGEMENTS

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VII. REFERENCES

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